Mapping rainwater management strategies at landscape scale

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1 Introduction

Most farmers in sub-Saharan Africa depend mainly on unreliable rain fed agriculture and are vulnerable to climate variability. The lack of water management in these areas prevents smallholders from addressing consequences from droughts and explains to a large extend the prevailing food insecurity and poverty (Hanjra, Gichuki, 2008; De Fraiture et al., 2010).

Integrated rainwater management is a recently developed concept that abandons the differentiation between irrigated and rain fed agriculture (Humphreys et al., 2008; Rockström et al., 2010; 2003). It encompasses any bundle of practices that aims at increasing rainwater productivity or retention and includes practices such as increasing soil water holding capacity, enhancing crop and livestock water productivity, improving efficiency of small scale irrigation, efficient use of ground water wells, diversion, or water harvesting (Johnston, McCartney, 2010; Rockström et al., 2010; Brown, Hansen, 2008; Hanjra, Gichuki, 2008).

Whereas adoption and socio-economic impact of single practices are relatively well understood, there is a lack of understanding which practices needs to be bundled in order to optimize water retention or water productivity within the watershed at landscape scale. Furthermore, locations suitable for a bundle of practices, also referred to as a strategy, in terms of bio-physical, socio-economic and institutional aspects are yet unknown.

The objective of this paper is to define a rainwater management strategy at landscape scale, and present a methodology to identify suitable locations for various rainwater management strategies. The methodology is illustrated with one rainwater management strategy in the Blue Nile Basin.

2 Definition of rainwater management strategy at landscape scale

In this paper we define rainwater management practices, hereafter referred to as practices, as anything done by an actor, whether it is a farmer or a community to increase water retention or water productivity within the watershed. If fundamentally assumes that an actor takes the decision to do something. An intervention is anything done by a government or ngo's or any other actor to initiate a practice change. Note that these definitions differ from the ones used in environmental sciences where the word *intervention* refers to any practice that intervenes on the landscape structure and therefore corresponds to our use of the word *practice*. Based on these definitions a rainwater management

strategy is a bundle of rainwater management practices that maximize (increase ?) water retention or water productivity within the landscape.

Because many practices have impact on what happens some kilometers downstream, it makes sense to look at practices with a landscape approach. A landscape is a proportion of heterogeneous territory composed of sets of interacting ecosystems that are repeated in a similar fashion in space. In the context of rainwater management, it makes sense to look at the landscape as a micro-catchment (or sub-basin) that is formed of a top slope (zone 1), a middle slope (zone 2) and the bottom valley (zone 3) as shown in Figure 1.

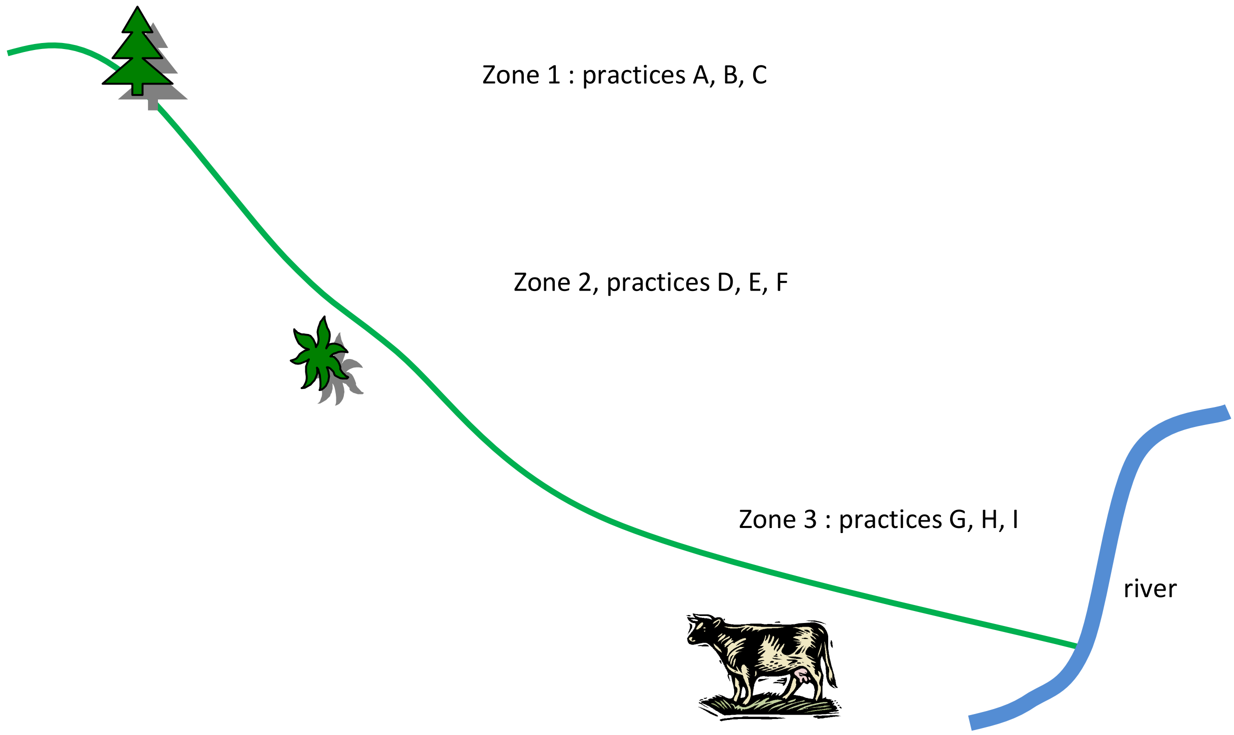

Figure 1 : schematic representation of a landscape with the three relevant zones : top slope (zone 1), middle slope (zone 2), bottom valley (zone 3).

From this perspective, a rainwater management strategy at landscape scale corresponds to bundle of practices that cover the whole gradient of the landscape and maximizes water retention or water productivity within the landscape (micro-watershed or sub-basin). In terms of Figure 1, example for a rainwater management strategy at landscape scale could be expressed as practice A in zone 1, practice E in zone 2 and practice G in zone 3, whereas a rainwater management strategy at farm scale would be practice D and F in zone 2.

By using the landscape as observation unit (scale) for assessing rainwater management strategies, heterogeneity within the landscape is lost. This implies that synergies between different practices within the landscape (downstream impact) are considered to be the same in all the landscapes within the basin.

However, downstream impacts from one landscape on another landscape can potentially be assessed with a hydrological model.

3 Overall modeling approach

In order to identify location where a given rainwater management strategy is most likely to succeed, the approach shown in Figure 2 is proposed. It consists of 4 modules: A. participative selection of promising practices, B. identification of biophysical drivers and socio-economic and institutional conditions C. transforming drivers (identified in B) into spatially explicit variables, D. maps RMS at landscape scales, by mapping suitability for individual practices and overlay them.

Module A aims at identifying practices that have most potential in terms of rainwater retention within the basin. These can be identified based on literature and expert knowledge. One option is to present a list of potential practices and ask stakeholder to rank them. In a second stage, stakeholders can be asked which of these promising practices need to be combined with other practices at different location within the landscape in order to increase the water retention within the watershed. The resulting suite of practices is a promising rainwater management strategy at landscape scale.

Module B identifies bio-physical success conditions as well as socio-economic and institutional driver for each of the practice that forms the promising rainwater management strategy identified in module A. This can be done by combining literature review as well as expert knowledge.

Module C transforms the conditions and drivers identified in module B into spatially explicit variable (geographical layers). For each variable a relevant threshold needs to be defined in order to identify suitability areas. Two different types of variables can be distinguished: variables based on a killer criterion and variables based on a soft criterion.

Variables based on a killer criterion are variables that are necessary conditions for a practice for being suitable. These variables are modeled as binary maps indicated areas of suitability and areas of non-suitability. The relevant threshold for defining what is suitable and non-suitable can be selected based on literature review and expert knowledge.

Variables based on a soft criterion represent drivers which increase or decrease the adoption of a given practice, without being a necessary condition. These variables cover a range of values that need to be normalized to a variable between 0 and 1. It can be used to compute a probability of adoption with the areas that have been suggested as suitable by the variables based on a killer criterion.

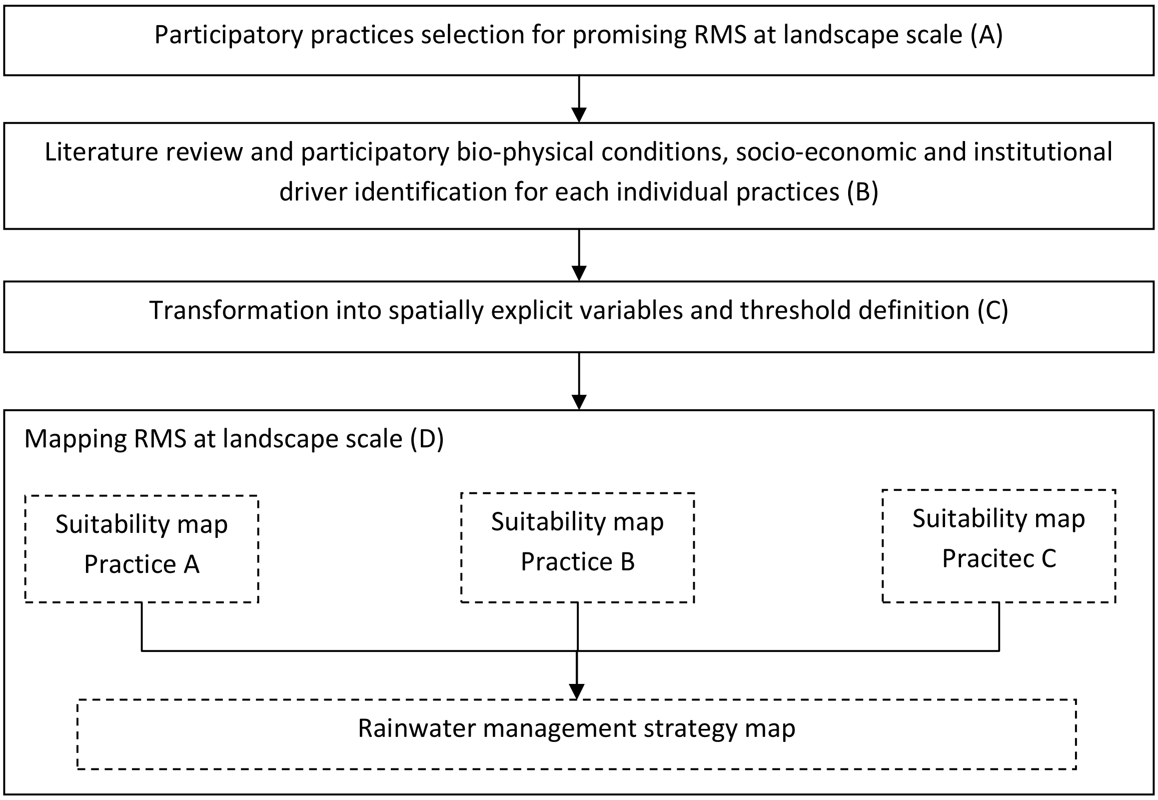

Figure 2 : proposed approach to identify suitable locations for rainwater management strategies at landscape scale within the Blue Nile Basin

Module D maps the RMS at landscape scale by first creating suitability maps for each individual practice by making use of the previously identified variables (module C) resulting from the identified drivers (module B).

Whereas variable based on a killer criterion can be simply overlaid to identify suitable locations, variables based on a soft criterion need to be aggregated. Weights of importance for each variable needs to be allocated. These weights can be defined based on existing literature or expert knowledge.

Finally, the suitability maps for each practice can be overlaid, identifying "hotspots" where different practices can be applied within the basin. These hotspots indicate locations suitable for rainwater management strategy.

4 Application to the Blue Nile basin

4.1 Study area

This approach has been applied to the Blue Nile basin in the Ethiopian highlands (Figure 3) for which one promising RMS is modeled as illustration (and test) of the framework. The study sites, namely Jeldu, Diga and Fogera are of particular interests as detailed data is available that can be used for validation of the suitability maps.

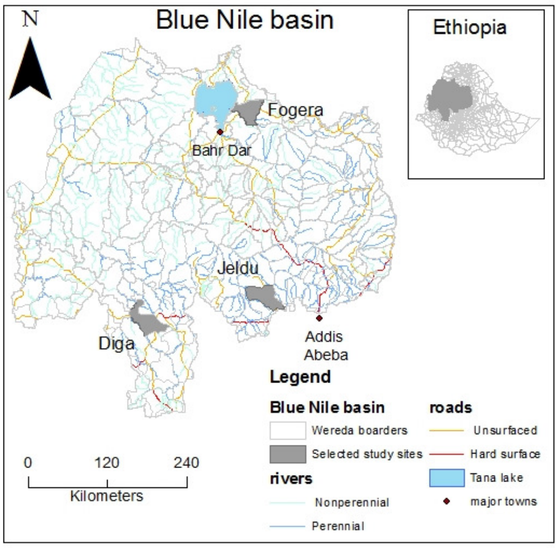

Figure 3 : The Blue Nile Basin with the selected study sites for the NBDC program

4.2 Data collection

4.2.1 Available secondary data

Many spatial datasets are available for Ethiopia and cover many bio-physical characteristics such as elevation, temperature, rainfall, slopes, rivers, roads. Also the last population census has been geo-referenced at woreda (district) level and allows to map socio-economic and some institutional characteristics of Ethiopia (-, 2006). Also a travelling time to major markets have been mapped (Schmidt, Kedir, 2009).

Finally, a recent study made use of available spatial data to run a factor analysis at woreda level within the Blue Nile basin (Pfeifer et al., 2011). This study identified 9 factors that represents within which the different woredas within the basin differ, namely drought potential, school density, remoteness, rainfall erosion potential, agricultural dependency, off-farm income, population pressure, small female headed households and access to services. These factors can be mapped and have the advantage to be uncorrelated among each other's.

4.2.2 Data from the study sites

Data is being collected from the three study sites, namely Jeldu, Diga, and Fogera. This data, when available can be used to validate the similarity maps.

4.2.3 Stakeholder workshop

A stakeholder workshop that included representative from the regional research institutes from Oromia and from Amara as well as the Ethiopian water harvesting association has been run. These stakeholders have been selected because they are the one doing research to inform extension services and NGO's about best bet practices to promote.

During the workshop a list of practices observed in the Blue Nile Basin has been done and completed with practices identified through literature that the stakeholders would accept as possible option for the area. In groups the stakeholders where then asked to rank the practices and choose the ones they think have the most potential in terms of changes in smallholders' livelihood. These practices were agro-forestry (fruit trees and multi-purpose trees), micro-irrigation schemes and water harvesting structures that allows for supplemental irrigation, soil moisture conservation practices (bunds, terraces, …) and conservation agriculture (minimum tillage).

For the mentioned practices stakeholders were asked to come up with the bio-physical conditions as well as socio-economic and institutional conditions for success.

4.3 Applying the various modules

4.3.1 Participative selection of practices (A)

The practices with most potential have been matched with the definition of rainwater management strategy presented in Figure 1. One practice per zone has been chosen to illustrate the proposed approach, namely fruit trees for zone 1, terracing for zone 2, and traditional river diversion zone 3.

Fruit trees as well terracing are two practices that might take very different forms within the basin based on bio-physical characteristics. Therefore in order to have options that cover the whole basin, these practices need be differentiated into sub-categories. Fruit tree have been divided into apple tree that need cool climate, and mango trees that cope with a more temperate climate. Terracing has been differentiated into bench terraces and hillside terraces as they suit different rainfall patterns.

4.3.2 Identification of bio-physical drivers and socio-economic and institutional drivers (B)

Driver for each of the 5 selected practices, namely apple tree, mango tree, bench terraces, hillside terraces and river diversion, have been identified by combining expert knowledge collected during the stakeholder workshop with drivers collected through literature review. Table 1 shows the identified bio-physical conditions as well as the socio-economic and institutional characteristics for each practice, as well as the source from which the respective driver has been identified.

Table 1 : bio-physical conditions and socio-economic and institutional characteristics for the selected practice

Practice	Biophysical characteristic	Socio-economic characteristics	Institutional and other characteristics
Apple tree	Minimum temperature bellow 20 (o. A., o. J.; o. A., o. J.) Drained soils (Carter, o. J.) Plot size (Corbeels et al., 2000) No drought	Access to a short supply chain (expert)	Tree nursery (expert) Land certification (expert)
Mango trees	Top-middle slope Nitisol Dryer climate (o. A., o. J.) Plot size (Corbeels et al., 2000) No drought Fertilizer	Access to a short supply chain (expert)	Tree nursery (expert) Land certification (expert)
Bench terracing	Semi-arid to medium rainfall Deep and drained soils Slope between 12-58% (Lakew et al., 2005)	Labor availability (Lakew et al., 2005)	Social capital for communal work (expert) Land certification (Omiti et al., 1999) Access to advice (Schmidt et al., 2010) Off-farm income (Holden et al., 2004)
Hillside terracing	Arid and semi-arid slope to 50% (Lakew et al., 2005) plot size (Schmidt et al., 2010)	Community labor (Lakew et al., 2005)	Social capital Land certification Access to advice (Schmidt et al., 2010) Off farm income (Holden et al., 2004)
River diversion	Perennial river (expert) Accessible land (expert) Less permeable soils (expert)	Access to capital and advice (expert) Family labor (expert)	Authorization of the water ministry (expert)

4.3.3 Transformation of drivers into variables (C)

The identified drivers in Table 1 need to be transformed into spatially explicit variable so that areas of suitability can be defined. Unfortunately for some of the drivers, such as proximity to tree nursery, land certification or social capital, there are no variable that can be used for mapping. Therefore Table 2 shows only the variables selected. Table 1 also indicates if the variable is based on a killer criterion or a soft criterion. For the killer criterion, the used threshold is indicated. These thresholds have been selected based on the information source indicated in Table 1. For river diversion, two and half kilometer threshold as been chosen based on observations in the fields (Jeldu). For market access 8 hours to major market has been used, similarly than the Gates foundation project. For the soft criteria variables have been normalized. Plot size less than 1 ha, access to advice and access to credit, are in terms of percentage of households and therefore have been kept as such.

Table 2 : variable chosen to model the drivers identified in Table 1

Practice	Biophysical characteristic *= killer criteria	Socio-economic characteristics **= soft criteria	Institutional and other characteristics
Apple tree	Minimum temperature below 10c* Luvisol, nitisol, leptosol Drought potential (factor) < high*	Market access less than 8 hours* Plot size > 1 ha **	
Mango trees	Nitisol* Sub-humid zone*	Market access less than 8 hours* Plot size > 1ha **	
Bench terracing	Semi-arid and sub-humid zones* soils drainage ≠ poor* Slope between 12-58%*	Norm. hh size**	Access to advice ** Normalized land fragmentation ** Agricultural dependency**
Hillside terracing	Arid and semi-arid* slope 10- 50%*	Norm Population density** norm. household size** plot size >1 ha **	Access to advice ** normalized fragmentation** Agricultural dependency**
River diversion	2.5km around perennial river* soil texture = fine*	Access to capital** Normalize hh size**	Access to advise**

4.3.4 Identify locations for RMS at landscape scale (D)

4.3.4.1 Suitability maps for each selected practices

In order to create the suitability maps for the selected practices, the variables presented in Table 2 need to be aggregated. Since no expert knowledge is available, each of the variables for one suitability map is assigned an equal weight.

Figure 4 shows the suitability maps for each of the 5 practices. A colored pixel indicates locations that are suitable for the given practices. The intensity of the color indicated locations that are more suitable in terms of the soft socio-economic and institutional criteria compared to other suitable areas.

Whereas apples are mainly suitable in the East of the country in the Highlands, mangos are more suitable in the warmer West. River diversion can only take place near to a river and are most suitable in highly populated areas. Terraces are mainly suitable on steep slopes in the highlands. Bench terraces are also suitable on less steep slope and therefore are also suitable on some spots in the West. The five practices can be overlaid, showing “hotspots” of suitable practices.

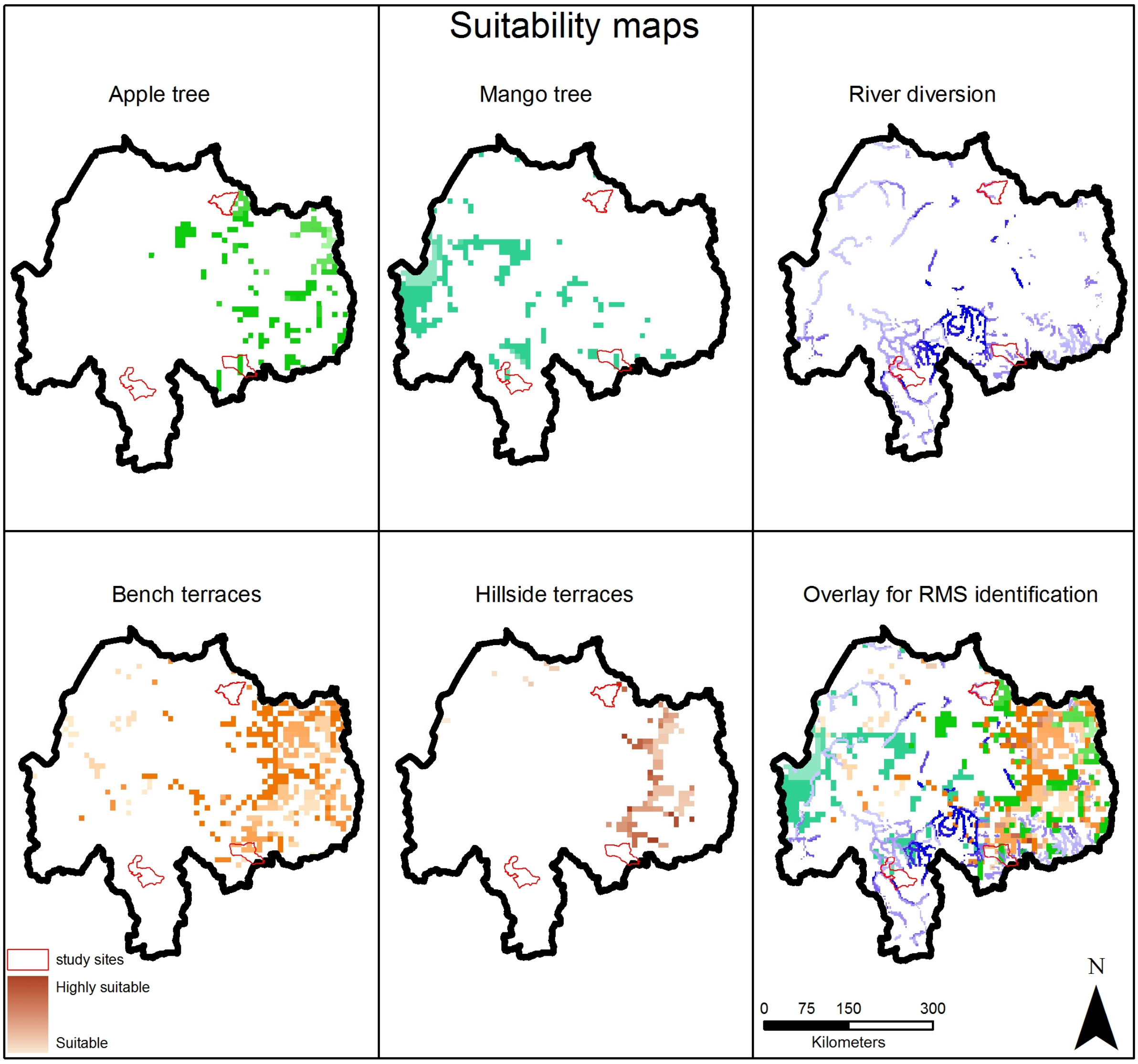

Figure 4 : suitability maps for apple tree, mango tree, river diversion, bench terraces and hillside terraces as well as the overlay of the 5 practices

4.3.4.2 Suitability maps for RMS at landscape scale

Suitable locations for a given RMS at landscape scales are areas (landscapes) within which practices from the 3 different zones (Figure 1) are suitable, and therefore form a rainwater management strategy. For this study, Blue Nile sub-basins have been as unit of aggregation for the practices to represent that landscape. The grey zone in Figure 5 indicates the four sub-basins which are suitable for the strategy agro-forestry – terracing – river diversion form a RMS at landscape scale.

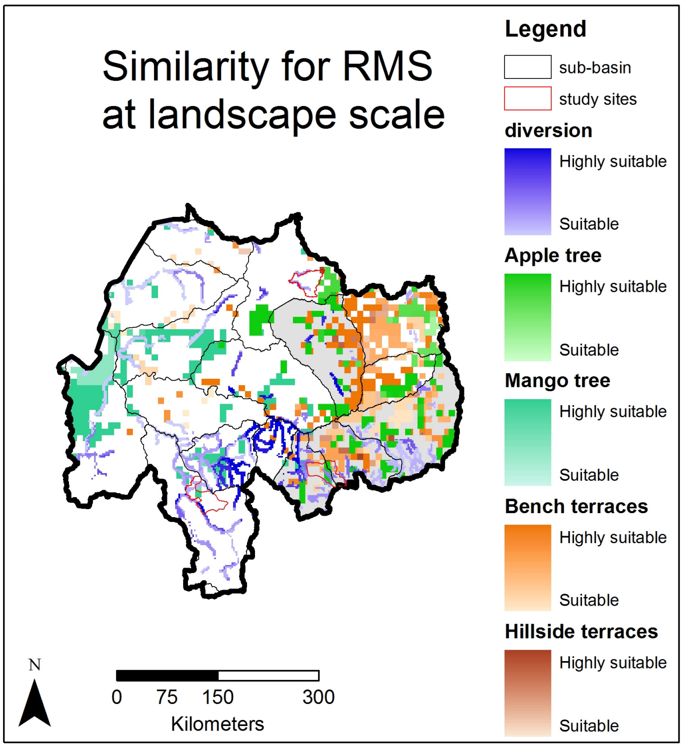

Figure 5 : Suitability of rainwater management strategies at landscape (sub-basin) scale

5 Discussion

This paper presents a test run of a modeling approach allowing to map rainwater management at

landscape scale. This test run has technically some limitations. Firstly equal weight have been attributed to each criteria used for a given suitability map. This implies that for a variables used for different suitability maps, its weight will depend on the number of other variables included and is not similar to each practices.

Secondly, some of the variables based on a soft criterion have been normalized so that all observations have a value between 0-1. Different variables have been normalized differently: by using the percentage of all smallholders, by using the maximum observed value within the Blue Nile basin, by using the maximum observed value within Ethiopia. Both weight used and normalization procedures needs to be carefully reviewed and analyzed on their sensitivity. Despite of these limitations, the presented approach yield suitability maps per practices that seem to make sense at least on the 3 study site from NBDC for which detailed information is available.

Thirdly, some variables that expert and literature suggested as very important namely land certification and social capital, could not be mapped. Future research could focus on mapping these two variables. A

land certification map could be done based on expert knowledge, whereas social capital could be mapped with similar techniques than poverty mapping (Davis, Nations, 2003) based on household's contribution to Iddir, the Ethiopian funeral societies, that insures people to cover funeral costs and seems to reflect social capital well (Dercon et al., 2008).

Fourthly, this paper defines the landscape scale as a sub-basin of the Blue Nile basin, mainly due to the availability of this map. These areas are pretty big and therefore it might be useful to come up with another definition of a landscape that is both makes sense and useful in terms of modeling. A hydrological response unit might be an interesting concept to identify the landscape scale and would allow to link suitability maps to hydrological models.

Finally, for future research, two major challenges need to be considered in order to be able to assess impacts and define interventions (what needs to be done to initiate a practice change). Firstly the presented suitability maps indicate where it makes sense to adopt a given practice. In fact, one does not know if the given practice is already adopted or if the some intervention is needed to promote that practice. An interesting path to follow is to investigate options to map current adoption of given practices. The gap between suitability map and adoption map allows to identify the window of opportunity for impact within which interventions should take place. Secondly, once the window of opportunity is identified, interventions that suit the local priorities must be designed. One option to link specific practices to institutional arrangements is to look at ecosystem services from water related activities as a transaction within the community as well as between up-stream downstream communities. In this perspective, institutional economics (Williamson, 2000), mainly transaction cost theory (Williamson, 2005) offers a promising approach to both set the incentives right so that strategies can be achieved within a landscape as well as investigation option for benefit sharing such as payment for ecosystem services.

Next steps consist of defining development domains as well as scenario definitions. Development domains are areas, in our case landscapes, which face similar constraints and priorities as well as similar potentials. These development domains depend on the selected rainwater management strategies and their connected interventions that define the priorities, the suitability maps that incorporate the constraints, and the potential economic and environmental impact (potential). Scenarios, within this context, can be consist of the implementation of a strategy within a given landscape and assess its hydrological impact on landscapes downstream. In iterative steps hydrological impact within the whole basin could be assessed.

6 Conclusion

This paper proposes a definition of a rainwater management strategy at landscape scale, as a bundle of practices chosen across the gradient of a landscape to maximize water retention within the watershed. A mapping procedure that allow to identify landscape where the given rainwater management strategy is

suitable is presented. It is applied to the strategy “agro-forestry-terracing-river diversion” in the Blue Nile basin.

7 References

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